ON THE ORIGIN OF SOLAR CYCLE PERIODICITY

ATTILA GRANDPIERRE
Konkoly Observatory, P.O. Box 67, H–1525, Budapest, Hungary
electronic mail: grandp@buda.konkoly.hu

(Received 1 July, 1996; accepted 22 October, 1996)

Abstract. Recently, the origin of the solar cycle is considered to be rooted in the dynamics of the solar core (Grandpierre, 1996). The dynamic solar core model requires macroscopic flow and magnetic field as basic inputs. The macroscopic flow cannot be generated by the quasistatic solar structure and it has to reach a larger than critical size (Grandpierre, 1984) in order to survive dissipation. Therefore the flow must be generated by outer agents. The most significant outer agents to the Sun are the planets of the Solar System. These theoretical arguments are supported by observations showing that planetary tides follow a pattern correlating with the solar cycle in the last three and a half centuries (Wood, 1972; Desmoulins, 1995). Therefore the pulsating-ejecting solar core model gives a firm theoretical basis for the interpretation of these largely ignored observations. In this paper a new and simple calculation is presented which enlightens the planetary origin of the eleven-year period and gives a physical basis for a detailed modelling of the dynamo and the solar cycle.

1. Introduction

Shortly after discovering the existence of the eleven-year-period in sunspot numbers, planetary theories were suggested to explain the origin of the solar cycle. Already Edmunds (1882) suggested that the periodicity of sunspot formation was controlled by the relative positions of Jupiter, Venus and the Earth. A review of planetary influences on solar activity is given by Gribbin and Plagemann (1977) and Seymour et al. (1992).

Recently, it was Wood, K.D. (1972) who realised that the rates of changes in the tidal heights of Venus, Earth and Jupiter – the so-called tidal fluctuations – remarkably correlate with the sunspot number in the last centuries. Wood, R.M. (1975) pointed out, that the origin of this period is related to the co-alignments of the planets Venus, Earth and Jupiter. He used computer-generated conjunction-opposition data from 1930–1960, and showed, that a small change in planetary synodic period can lead to a large change in the value of an approximate triple-alignment, e.g. a 0.1% change in a synodic period like that of Earth-Jupiter co-alignments changes the three-fold co-alignment periods between 20.40 to 24.49 yr. A similar sensitivity is present in the two-fold co-alignments as well.

Hantzsche (1978), misinterpreting the arguments of Wood (1972), argues against a purely tidal planetary theory. Nevertheless, as Wood (1972) himself remarked, “the best physical explanation is not, I believe, a delayed tidal effect, but . . . some nontidal factor contributing to the formation of sunspots”. The basic suggestion of my paper is that this nontidal factor is the local magnetic field present in the solar core. Moreover, as this factor evolves partly independently from the tides, the solar

Astrophysics and Space Science **243:** 393–400, 1996.

activity is regulated by the interaction of the magnetic field and the tidal function, which enhances the irregular character of the process.

Seymour, Willmott and Turner (1992) presented detailed calculations based on Seymour's canal tidal theory. They argue that the active regions form a magnetic canal for the tidal waves, resonantly amplifying them at the top of the convective zone in dependence of the phase of the solar activity cycle. Recently, Desmoulins (1995) presented results showing the relation of the solar cycle to the planetary co-alignment periods on the basis of numerical calculations of planetary tides. He applied 'quality signals' describing the syzygies and their durations. He suggested that the cause of the correlation of planetary co-alignment periods with the solar activity indices is the interaction of gravity waves and magnetohydrodynamical processes in the solar core.

Planetary tidal effects are extremely small compared to the Sun's own gravitation. Therefore, we can only give a physical basis to the observed correlation of planetary alignments and solar activity if a sensitive amplification of planetary effects existed, since their amplitude compared to the solar gravitational field is characterised by a ratio of 10^{-12}. Moreover, the present view of the solar physicists' community is that solar activity is generated in the outer regions of the Sun. Babcock's (1961) atmospheric dynamo theory of solar activity considers two basic factors, one is the convection in the subphotospheric convective zone of the Sun and the other is the global rotation. Both of them are insensitive to planetary influences, therefore the idea of planetary effects on solar activity seemed to be largely sterile and irrelevant.

At the same time, the atmospheric dynamo theory is not able to explain the 11-year-period in a consequent way. T.G. Cowling's objection against all dynamo models is that small sections of poloidal field are linked to form a larger-scale field. The mechanism involved is turbulent diffusion. This results in the mixing of magnetic field elements, not in their joining up, which can only be done through the diffusion or reconnection of the field lines. But in the highly conducting gas of the deep solar interior magnetic diffusion and reconnection proceed extremely slowly, on a time-scale of 5×10^8 yr, much too slowly to explain the Sun's eleven-year cycle (Phillips, 1992, p. 70).

If the dynamo works at the bottom of the convective zone, as it is nowadays generally assumed, then the magnetic field lines have to change their direction in every 11 years at that depth. But in the atmospheric dynamo models this process either should be related to a reversal of the helicity of the convective elements, which is not observed, or to a change of sign of the differential rotation, for which no physical mechanism is suggested. At the same time, helioseismic observations do not indicate such changes in the rotation of the solar envelope but they suggest changes in the rotation rate of the solar core in an apparent correlation with the solar cycle (Dziembowski, Goode, 1993). These arguments give independent evidences for the core origin of the dynamo mechanism.

It is an interesting fact, that most planets of the Solar System which have one or more significant satellites, also have a significant magnetic field. This seems to be the case for the Sun as well if its magnetic field generation is related to the planets as it is suggested here on the basis of the pulsating-ejecting solar core model (Grandpierre, 1996). Remarkably, Novotny (1983) pointed out that a linear relation exists between the magnetic moments of the planets and the radial velocity of tidal deformations generated by their satellites. He obtained a nearly linear relation between the planetary magnetic moment M and $Q = \rho R^2 \omega \xi$, where ρ is the density in the core of the planet, R is its radius, ω is its angular velocity, and ξ is the amplitude of the tidal deformation. The slope of this linear relation is close to unity, i.e.

$$M \simeq \rho R^2 \omega \xi \tag{1}$$

This indicates that a relationship may exist between planetary magnetism and tides, as Novotny wrote, "although the appropriate physical mechanism is not known". The state of affairs has changed with the appearance of the pulsating-ejecting solar core model, suggesting a concrete physical mechanism for the generation of the magnetic cycle (Grandpierre, 1996). The connection of planetary magnetism and tidal deformation waves is clarified by Dobrolyubov (1991). He showed that travelling deformation waves have the capacity to transport mass. The mass transport of tidal waves in the interior of the Earth is suggested to be the driving mechanism of the geomagnetic dynamo (Dobrolyubov, 1993). I suggest, similarly, that the mass transport of tidal waves in the solar core drives the solar dynamo. Interpreting the Novotny-relation, we suggest that since $M \simeq B \times R^3 \simeq I \times R^2$, where B is the magnetic field induced in the planet, R is its radius, I is the equivalent dipole current producing the same field at the surface, therefore from (1) we get

$$I \simeq \rho \omega \xi \tag{2}$$

which seems to be a resonable argument, as any current generated by tides has to be proportional with the plasma density and the tidal amplitude, and the dynamo efficiency is related to the rotation rate.

One can think that the theory described here suggests a significant magnetism of the Moon generated by the large tide exerted by the Earth, and this consequence is objected by the fact that the Moon has a very weak magnetic field. Nevertheless, one has to keep in mind that the rotation of the Moon is fixed to the Earth, and therefore the tide exerted by the Earth does not move relative to the Moon and so cannot participate in the magneto-tidal dynamo. This means that we have to put $\omega - \omega_0$ in Equation (2) instead of ω, where ω_0 is the angular velocity concerning to the orbital rotation rate.

2. Calculations of the Periods of the Magneto-Tidal Mechanism in the Solar Core

My attempt is to show that, contrary to the presently generally accepted views:

a.) the planetary tides may exert a significant physical influence on the Sun. Although the tidal heights are small, cca. 0.16 cm, their velocity is significant as a consequence of larger gravity, reaching 93 cm/s, as compared to the 320 cm/s tidal velocity of the tides generated by the Moon on the Earth (Opik, 1972). Moreover, these apparently small effects are able to generate a significant change in the solar energy production because of the positive feedback mechanism present in the solar core. Any macroscopic flow in the energy producing core, when interacting with a local magnetic field, generates electric field, producing local heating. The nuclear fusion reactions proceeds on the high power of temperature, therefore the tidal-MHD heating will be accelerated, generating local thermonuclear runaways (Grandpierre, 1990, 1996). These thermal runaways grow in size until they reach a critical value when they are shooted outwards from the core towards the surface, producing the activity-related phenomena;

b.) in this way, the tidal flows, when their effects (duration, amplitude, interactions) reach a certain threshold in some relevant combination with the local magnetic field, may generate processes which are related to the surface emergence of new sunspots (Grandpierre, 1996).

I calculated the periodicities present in the co-alignments of Earth, Venus and Jupiter. Now, regarding the planets and the Sun as mass points, alignment occurs when the two planets and the Sun determine a common straight line. We have to calculate the approximate threefold alignments since they play an important role in the generation of high tides on the Sun. We selected the paired alignments when the third planet is close to the other two within ten degrees. Therefore we determined three periods. The one which refers to the cyclical alignments of the Venus-Earth pair with the Jupiter within ten degrees, is denoted as $t_{VE,J}$ (the others are $t_{VJ,E}$ and $t_{EJ,V}$, respectively).

The calculation of $t_{VE,J}$:

The period of alignments of Earth and Venus is $t_{EV} = T_E * T_V/(T_E - T_V) =$ 1.5987 yr, therefore, regarding conjunctions and oppositions as well, $t_{EV1/2} =$ 0.799 yr. Starting from a threefold alignment, after one revolution of an Earth-Venus co-alignment, which needs a time $t_{EV1/2}$, the Jupiter will lag behind them with an angle of $t_{EV1/2} * 360^0/T_J = \alpha_J = 83^0.51$. This means that the Jupiter will be within a ten-degree region after 13 revolution ($5^0.64$), 15 revolution ($-7^0.34$) and 28 revolution ($-1^0.66$). Strict repetition of the original co-alignments never occurs but the alignments have a kind of 'attractor', which is the time period around which the threefold alignments spread. This theoretical 'attractor' period $t_1 = t_{VE,J}$ may be determined by linear interpolation, $t_1 = t_{VE,J} = 11.395$ yr. We can also observe the existence of two sub-periods; one after 13 revolution, i.e. $t_{1a} = 10.387$ yr, and another after 15 revolutions, i.e. $t_{1b} = 11.985$ yr. These sub-periods involve approximate alignments within ten degrees.

The calculation of $t_{VJ,E}$:

Similarly, we found that $t_{VJ1/2} = 0.3244$ yr . The alignments will be within ten degrees after k = 5 revolutions ($\alpha = 5^0.266, t_{2a} = 1.6221$ yr), k = 27 revolutions ($\alpha = -7^0.55, t_{2b} = 8.7588$ yr), k = 32 revolutions ($\alpha = -2^0.30, t_{2c} = 10.3808$ yr), k = 37 revolutions ($\alpha = 2^0.97, t_{2d} = 12.003$ yr) and k = 42 revolutions ($\alpha = 8^0.232, t_{2e} = 13.625$ yr). The attractor period is $t_2 = t_{VJ,E} = 11.398$ yr. The close coincidence of these two periods $t_{VE,J}$ and $t_{VJ,E}$ is remarkable.

The calculation of $t_{EJ,V}$:

Similarly, $t_{EJ1/2} = 0.546$ yr, and the alignments will be within ten degrees after k = 18 revolutions ($\alpha = 9^0, t_{3a} = 9.828$ yr) and k = 20 revolutions ($\alpha = -9^0, t_{3b} = 12.012$ yr). Therefore, $t_3 = t_{EJ,V} = 10.92$ yr.

3. Discussion

The results show that if the influence of the planets is actually present in the solar activity then a periodicity should exist which is not strict but scattered around the attractor value, sometimes coming sooner, sometimes later than the average periods calculated above.

Actually, the three calculated periods co-operate in the generation of the solar cycle. Most frequently, the co-alignments of the three cycles quickly follow each other in the same co-alignment interval. But the differences of the three periods cause a slow shift of the co-alignments relative to each other. After a certain number of cycles the co-alignment of the Earth-Jupiter system with Venus within ten degrees is not accompanied by a co-alignment of the Venus-Earth system with the Jupiter (within ten degrees) or with a co-alignment of the Venus-Jupiter pair with the Earth (within ten degrees). The threefold co-alignments are replaced from time to time with a twofold co-alignment (within ten degrees). A new threefold co-alignment will start at a different position of the planets with a time shift determined by the shortest period, i.e. 10.92 years. Actually, the interplay of the three cycles has an effect on the solar cycle with a period somewhat longer than 10.92 years, since the twofold and threefold co-alignments influence the amplitude and duration of the tidal maximums. The effect of co-alignments determines a tidal solar cycle period ranging between 10.92 and 11.398 years. Based on the above argumentation, it is clear that the value of this period is closer to the 10.92-year period, it is approximately 11.1 years.

The actual value of the magnetic field in the solar core will significantly modify the timing of the actual solar activity maxima and minima, although this effect will average out in the long run. So we can expect an average value for the solar activity as being close to $t_{av} = 11.1$ yr. Observations show a close agreement with that value.

It is interesting to note here that the existence of the 10.4-year period in the alignments of the tide-raising planets within ten degrees, which is considered by Okal and Anderson (1975) as a common phenomenon, goes back in the frame of our calculation to the existence of the sub-periods $t_{1a} = 10.387$ yr and $t_{2c} = 10.381$ yr. But now we see all the periods and sub-periods being present in the alignments of these three planets. Although "an alignment within ten degrees is not associated with drastic tidal effects", as Okal and Anderson (1995) noted, it is almost as 'drastic' as a perfect alignment, and, if associated with strong enough magnetic field in the core, it may certainly generate 'drastic effects' through the positive feedback present in the solar core (Grandpierre, 1990), i.e. local thermonuclear runaways.

Desmoulins (1995) determined sub-periodicities of the Venus-Earth-Jupiter system as 119, 238, 584, and 594 days. Our calculations show only a partial agreement with his results, indicating the existence of co-alignment intervals of 118.5 ($t_{VJ,1/2}$), 199.4 ($t_{EJ,1/2}$), 292 ($t_{VF,1/2} = 584/2$), 583.9 ($2 \times t_{VF,1/2}$), 592.4 ($t_{2b} - t_{2a}$) and 797.7 ($t_{3b} - t_{3a}$) days. It is interesting to note that $t_{1b} - t_{1a} = 583.7$ days, a value close to $2 \times t_{VF,1/2}$. Moreover, $t_{2a} \simeq t_{2c} - t_{2b} \simeq t_{2d} - t_{2c} \simeq 592.5$ days. The sub-periods contribute to the appearance of transient sub-cycles.

The results presented here offer a solid basis for a new type of dynamo model of the solar activity cycle. Now it is possible to work out a model in which the solar core produces a local thermonuclear eruption – which may lead to the appearance of a sunspot in the surface – if both the magnetic field and the tidal flow reach a critical amplitude, or when their product is larger than a certain threshold. This model suggests an indirect connection, mediated through many steps in between the core and the surface, therefore depending on these parameters as well, between the number of new-born sunspots (the birth rate) and the magnetic field and flow velocity amplitudes.

Accepting the arguments I gave here for the planetary origin of the solar cycle, the role of the other planets remains an open question. For example, Mercury has a gravitational influence similar to that of the above three planets Jupiter, Earth and Venus. As Verma (1986) has shown, the four-fold co-alignment period of these four planets occurs with a period of 66.4 years. It is interesting, that this period seems to be present in the solar activity, and has the largest amplitude after the 11.1 and 23.6 years values found by Currie (1973). Moreover, the threefold co-alignment periods of Mercury and Jupiter with Venus ($60t_{JM} = 23t_{JV} = 14.7$ yr, and $13t_{JV} = 34t_{JM} = 8.4$ yr, see Verma, 1986), and with Earth (9.9 yr) averages out again to 11.0 yr, underlining the above accepted results.

Our result has a fundamental significance in our understanding of solar and stellar activity and the origin of magnetic fields. It is clear, that if the satellite effect is real, we have to expect that differencies in the satellite's distances produce differencies in the activity parameters. Therefore, it seems to be necessary to check qualitatively the presence of the satellite-effect on the activities of binary variables. It is remarkable, that the Sun seems to possess active longitudes with a separation of 180 degrees (Dodson, Hedeman, 1972), consistently with our result that the solar activity is a global phenomenon, driven from the core and is related to planetary alignments which have a diametrically symmetrical effect on the core dynamo. It is clear that if flares are merely atmospheric phenomena, as e.g. earthly lightnings, then one would find it impossible to have a systematical correlation between events diametrically opposed on the surface of the Sun. On the other hand, the new starspots appear closely on the same phase of the rotation around the mass center of the stellar system, on the same position at the star's surface (Olah, Hall, Henry, 1991). If spots appear preferentially at a fixed orbital phase, they can not be produced by a dynamo driven merely by stochastic turbulence, but some deep-seated nest has to be present similarly to the earthly vulcanic hot spots. Furthermore, most of the single variables the starspots occur at a 180-degree separation, like in the case of AB Dor (Zeilik et al., 1988). In close binaries the separation of the active longitudes decreases, through 150-120 degrees in the surface of HK Lac to a close quadrature at the closest RS CVn binaries (Zeilik et al., 1989). These facts suggest strongly the existence of a deep-seated source of stellar activity and its relation to the satellite-effect at the generation of stellar activity phenomena.

4. Conclusion

I presented unignorable arguments on the reality of planetary effects on the solar activity. I pointed out, that the planetary tides are able to trigger explosive phenomena and dynamo mechanism in the solar core, and so planetary co-alignments are related to the solar activity. Therefore, the empirical coincidence of the presently found planetary co-alignment periods of 11.1 years and the long-time average period of the solar cycle is an additional evidence of the interconnectedness of the Sun with the planets, which is an indication of fundamental significance for dynamo theories.

Acknowledgement

This work is partly supported by the Hungarian Scientific Research Foundation OTKA under No. T 014224.

References

Babcock, H.W.: 1961, *Astrophys. J.* **133**, 572.
Currie, R.G.: 1973, *Astrophys. Space Sci.* **20**, 509.
Desmoulins, J.-P. 1995, *http://www.alpes-net.fr/~j_p_desm/sunspots.html*.
Dobrolyubov, A.I.: 1991, *Appl. Mech. Rev.* **44**, 215.
Dobrolyubov, A.I.: 1993, in: 'Moon and Living Matter', International Workshop, Kosice, Slovakia, September 23–25, 1993, Program and Abstracts, 19.

Dodson, H.W. and Hedeman, E.R.: 1972, in: P.S. McIntosh and M. Dryer (eds.), *Solar Activity Observations and Predictions*, Boulder, NAO, 19.
Dziembowski, W.A. and Goode, P.R.: 1993, in: T.M. Brown (ed.), *GONG 1992: Seismic Investigations of the Sun and Stars*, 225.
Edmonds, F.B.: 1882, *Nature* **26**, 292.
Grandpierre, A.: 1984, in: A. Noels and M. Gabriel (eds.), *Theoretical Problems in Stellar Stability and Oscillations*, 48.
Grandpierre, A.: 1990, *Sol. Phys.* **128**, 3.
Grandpierre, A.: 1996, *Astron. Astrophys.* **308**, 119.
Gribbin, J. and Plagemann, S.: 1977, *Jupiter Effect Revisited*, Fontana, Collins.
Hantzsche, E.: 1978, *Astron. Nachr.* **299**, 259.
Novotny, O.: 1983, in: A.M. Soward (ed.), *Stellar and Planetary Magnetism*, Gordon and Breach, New York, 289.
Okal, E. and Anderson, D.L.: 1975, *Nature* **253**, 511.
Olah, K., Hall, D.S. and Henry, G.W.: 1991, *Astron. Astrophys.* **251**, 531.
Opik, E.: 1972, *Irish Astron. J.* **10**, 298.
Phillips, K.J.H.: 1992, *Guide to the Sun*, Cambridge Univ. Press, 70.
Seymour, P.A.H., Willmott, M. and Turner, A.: 1992, *Vistas in Astron.* **35**, 39.
Verma, S.D.: 1986, in: K.B. Bhatnagar (ed.), *Space Dynamics and Celestial Mechanics*, D. Reidel, *Astrophys. Space Sci. Libr.* **127**, 143.
Wood, K.D.: 1972, *Nature* **240**, 91.
Wood, R.M.: 1975, *Nature* **255**, 312.
Zeilik, M., De Blasi, C., Rhodes, M. and Budding, E.: 1988, *Astrophys. J.* **332**, 293.
Zeilik, M., Cox, D.A., De Blasi, C., Rhodes, M. and Budding, E.: 1989, *Astrophys. J.* **345**, 991.